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LIFE CYCLE MANAGEMENT

Comparative life cycle assessment of reused versus disposable dental burs

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Abstract
Purpose Health care infection control has led to increased utilization of disposable medical devices, which has subsequently led to adverse environmental effects attributed to health care and its supply chain. In dental practice, the dental bur is a commonly used instrument that can be either reused or used once and then disposed. To evaluate the disparities in environmental impacts of disposable and reusable dental burs, a comparative life cycle assessment (LCA) was performed.
Methods The functional unit was defined as one reusable dental bur, where the maximum instances reused was 30 (or in the case of a disposable, the equivalent functional unit would be 30 disposable dental burs). The system boundary included all cradle-to-grave aspects of both single-use and reused burs, including raw material extraction, manufacturing, packaging, distribution, reuse, and disposal. Primary data included the following: operating parameters for ultrasonic cleaning, manual cleaning, and autoclaving of the burs. The secondary data for raw material extraction and production of dental bur and packaging were obtained directly from life cycle inventory databases. Sensitivity analyses were also performed with respect to ultrasonic and autoclave loading.
Results and discussion Findings from this research showed that when the ultrasonic and autoclave were loaded optimally, reusable burs had 40 % less of an environmental impact than burs used on a disposable basis. When the autoclave and ultrasonic were loaded to approximately two-third capacity, four environmental impact categories favored reusable burs (i.e., ozone depletion, smog, respiratory effects, exotoxicity), and four impact categories environmentally favored disposables (i.e., acidification, eutrophication, carcinogenics, and non-carcinogenics). When the autoclave and ultrasonic were loaded to approximately one-third capacity, reusable dental burs posed more negative environmental impacts in eight of nine environmental impact categories when compared to disposable burs.
Conclusions Operational efficiency of ultrasonic and autoclave cleaning equipment should be emphasized to enhance the environmental performance of bur reuse. In fact, improper loading of the ultrasonic and autoclave can lead to greater adverse environmental impacts than if the burs were treated as disposables. The environmental and economic impacts associated with bur reuse are expected to be similar with other dental devices that are designated as disposable but are capable of being reused (e.g., scalpels, forceps).

Keywords Dental burs · LCA · Reusable medical devices · Single-use devices (SUDs) · Sustainable health care · Sustainable material use

1 Introduction

Similar to the health care industry, the dental profession has seen a recent increase in the trend toward single-use disposal products and devices, where it is not entirely clear that the disposable nature of health care products is necessary or sustainable. Studies have estimated that individual dental practices generate over 600 L of waste and use almost 10,000 L of water on a weekly basis (Farmer et al. 1997; Farhani Suchak 2007). In 2007, the Eco-Dentistry Organization estimated that 1.7 billion sterilization pouches and 680 million patient barriers were disposed by US dental practices every year (Eco-Dentistry 2013).

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"Eco-friendly" dentistry initiatives have been implemented in recent years to reduce dental sector waste, as well as promote environmental awareness and sustainability in dental practices (Adams 2007). The objectives of these initiatives are to reduce the following: overall dental sector waste, mercury (and other toxic chemical releases into the environment), energy use, and water use (Eco-Dentistry 2013; Dental mercury pollution 2005). There are a range of best practices that can be adopted to meet the objectives of the eco-friendly dental initiatives. One study has shown that installing a central vacuum equipped with an amalgam trap will reduce mercury discharges to wastewater treatment plants (Adegbembo and Watson 2004). The Eco-Dentistry Organization has also recommended the following best practices: implementing an effective recycling program for waste materials (e.g., aluminum, glass, plastic, paper, steel) and X-ray solutions, using paint that does not include volatile organic compounds (VOCs), converting to high-efficiency lighting, and implementing an environmentally responsible supply chain sterilization program (Eco-Dentistry 2013).

The implementation of an environmentally responsible supply chain sterilization program entails maximizing instrument reuse when clinically suitable. In previous decades, dental supply chains shifted away from reusable devices and shifted toward single-use, plastic devices. This shift occurred in the early 1980s as concerns about pathogenic cross-contamination through device reuse were increasing (Greene 1986). Aside from infection control, use of disposable medical devices increased because of higher material complexity in technology and plastic manufacturing and ease of use and disposal (Greene 1986).

However, recent US Food and Drug Administration (FDA) studies show that the utilization of reusable devices does not correlate with an increased infection risk (Favero 2001; GAO 2008; US Food and Drug Administration 2009). The Government Accountability Office (GAO) concluded in 2008 that "[the] FDA's analysis of reported device-related adverse events does not show that reused [single-use devices] present an elevated health risk" (GAO 2008). This conclusion is based on the FDA's review of available adverse health events reported with reused [single-use devices], where no causative link was found between the adverse health events and utilization of reused devices (GAO 2008).

Since there are no risks related to infection control, reusable devices can be considered in the suite of best practices for sustainable dentistry. Dental practices can potentially reduce their environmental footprint by maximizing instrument reuse in their supply chains. The reduction in environmental footprint, however, is predicated upon proper execution of reuse protocols and procedures (Suter et al. 2009; Shuman and Chenoweth 2012; Hailey et al. 2008).

The aim of this study was to evaluate the environmental trade-offs between reused dental burs and dental burs used as disposables. Specifically, this study performed a comparative life cycle assessment (LCA) of reused and disposable stainless steel dental burs. Life cycle inventory collected for the analysis included the following: manufacturing, packaging, transport, reuse, and disposal processes associated with both single-use and reusable burs. A life cycle impact assessment (LCIA) was conducted using Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) v2.0 developed by the US Environmental Protection Agency (USEPA) (TRACI 2013). TRACI provides a range of environmental and human health impacts that will subsequently be interpreted.

The use of LCAs pertaining to reusable dental devices has not yet been investigated in the literature. Additionally, although hundreds of general health care devices are suitable for reuse, currently there are few LCAs focused on general health care devices. While there are no LCAs of dental products or procedures, a handful of LCAs have been performed on the wider sector of health-care-related products, including laryngeal mask airways (LMAs), medical waste containers, and catheter insertion kits (Eckelman et al. 2012; Overcash 2012; McGain et al. 2012). In addition, others have utilized LCAs to investigate hospital procedures, such as hysterectomies and C-sections (Bilec et al. 2012; Campion et al. 2012).

This study examines the reuse potential and related environmental impacts of dental burs from the Deer Valley Smiles dental office in Phoenix, AZ. The dental bur is used to remove tooth decay, shape tooth structure, and drill cavities in teeth of a specific diameter and depth. The bur that has been chosen for this study is shown in Fig. 1, which is the MIS Implants Technologies Ltd. 2.00-mm internal irrigation pilot drill. The 2.00-mm internal irrigation pilot drill was the only bur evaluated in this study.

Burs are a reusable dental product, where they typically undergo ultrasonic cleaning, manual cleaning, and autoclaving before reuse. First, ultrasonic cleaning removes excess debris. Then, the burs are usually manually cleaned under tap water with a scrubbing brush. Lastly, the burs undergo autoclaving, where autoclaving decreases pathogen levels to a point where the burs are suitable for clinical use.

Burs were chosen for analysis because they are widely utilized in all dental offices across the USA and around the world. Dental aides at Deer Valley Smiles dental office indicated that burs are used in high quantities because nearly every dental procedure involves any number of the previously stated

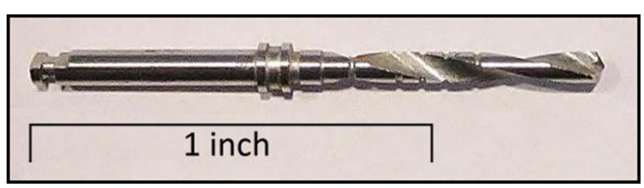

Fig. 1 MIS Implants Technologies 2.00-mm internal irrigation pilot drill

dental bur uses. Dental burs are also suitable candidates for reuse in dental offices because individual burs are expensive, ranging anywhere from US$70 to US$150 per bur; patient insurance will not cover any portion of a dental bur's costs; and burs are able to be reused up to 30 instances (particular to this study). There is no industry standard or factory recommendation for the number of bur reuse instances with respect to the MIS Implants Technologies Ltd. 2.00-mm internal irrigation pilot drill. The dentist indicated that a MIS Implants Technologies Ltd. 2.00-mm internal irrigation pilot drill's drilling efficacy and blade sharpness decreased with each procedure and that the burs would be disposed after reaching approximately 30 reuse instances.

2 Approach

2.1 Scope and system boundary

A comparative life cycle assessment was conducted for reused dental burs and single-use dental burs. The LCA methodology was performed using the basic methodological steps described by the International Organization for Standardization (ISO) 14040–14044 series (i.e., goal and scope definition, inventory analysis, impact assessment, and interpretation) (ISO 14040 1996). System boundaries are illustrated in Fig. 2, which depicts the cradle-to-grave aspects of both single-use and reused burs, including extraction of raw materials, manufacturing, packaging, distribution, reuse, and disposal. The functional unit was defined as one reusable dental bur, where the maximum instances reused was 30 (or in the case of a disposable, the equivalent functional unit was the production and disposal of 30 disposable dental burs).

To standardize the results, 30 reuse instances was assumed for all MIS Implants Technologies Ltd. 2.00-mm internal irrigation pilot drills at the Deer Valley Smiles dental office. With regard to this particular study, the MIS Implants Technologies Ltd. 2.00-mm internal irrigation pilot drill was assumed to be both disposable and reusable. This assumption was confirmed after consultation with the Deer Valley Smiles' dentist, who indicated that a proportion of dental offices outside of Deer Valley Smiles designate MIS Implants Technologies 2.00-mm internal irrigation pilot drills (or similar burs) as single-use disposables.

2.2 Inventory analysis

Life cycle inventory (LCI) data were collected from different sources. Primary data were collected from Deer Valley Smiles, which included the following: operating parameters for the ultrasonic cleaning such as volume of water used and energy consumed per cleaning, parameters for the manual washing including volume of water used, and operating parameters for the autoclave including water and energy used. Material composition of the bur was collected from information made publicly available by the bur manufacturer, MIS Implants Technologies. The secondary data for raw material extraction and production of materials such as the dental bur, electricity, and packaging were obtained directly from life cycle inventory databases including ecoinvent v2.2 and US Life Cycle Inventory (USLCI) and European Reference Life Cycle Database (ELCD). Other secondary information (i.e., bur specifications, disposal methodologies) were obtained directly from their respective manufacturers or service provider. The LCI data is described in more detail in subsequent sections.

One model of dental bur was analyzed: the MIS Implants Technologies Ltd. 2.00-mm internal irrigation pilot drill. Primary data with respect to the bur and its packaging materials were collected for only one bur. Material composition of the bur was determined from manufacturer information (MIS 2013). The bur's packaging materials are shown in Fig. 3, which shows the kraft paper and glass-fiber-reinforced plastic that constitute the bur's packaging. One of each packaging item and bur were weighed using an analytical scale with a 0.01 g detection limit, and this packaging inventory data is summarized in Table 1.

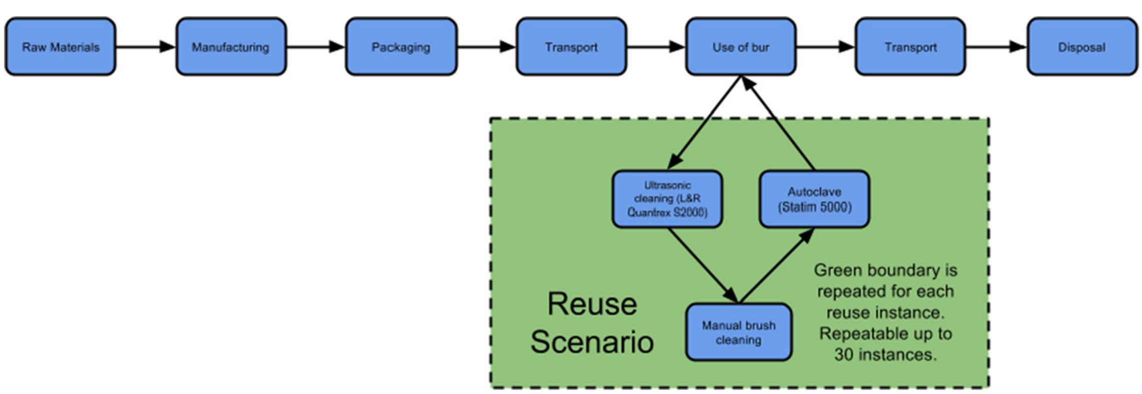

Fig. 2 System boundary showing processes included in the LCA. While not shown, the system boundaries include energy, materials, and emissions associated with each process

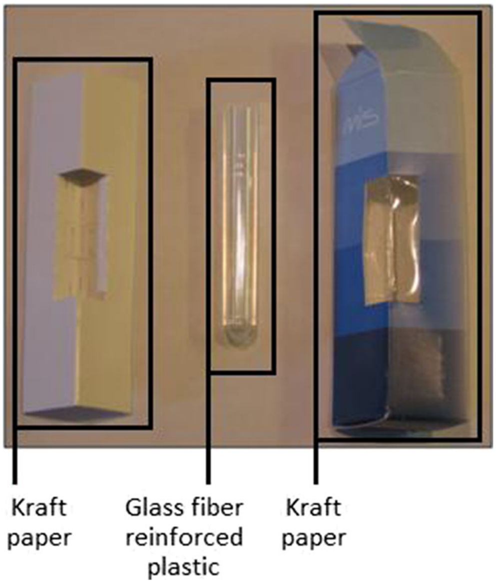

Fig. 3 Bur packaging materials. *From left to right*, kraft paper, glass-fiber-reinforced plastic, and kraft paper with plastic film

Certain operating parameters were specific to the Deer Valley Smiles dental office. These operating parameters included the following: form and method of reuse, instances reused per dental bur, method of disposal, and quantity of procedures performed. Additionally, the Deer Valley Smiles dental office staff considered themselves a typically sized office, where they would perform approximately 8–15 procedures on the same number of patients on a daily basis.

The data used to construct the bur's life cycle inventory is shown in Table 2. The materials and production processes were identified within the corresponding life cycle inventory records from the European Reference Life Cycle Database (ELCD) and US Life Cycle Inventory (USLCI) Database. The electricity mix for Arizona was not included in the ecoinvent database or existing life cycle inventory databases but was modeled using existing data provided by the US Energy Information Administration (EIA 2014). Specific to this study, the burs were manufactured in Minden, Germany, where the burs were transported via combination of truck and freight aircraft to the dental office in Phoenix. The burs were shipped roughly a distance of 700 km by truck from Minden, Germany, to Paris, France. The burs were then transported roughly 8,800 km by freight aircraft from Paris, France, to Phoenix, AZ. Lastly, the burs were transported a distance of 35 km from the Phoenix airport to the dental office. These distances were calculated using Google Earth v7 software. Upon arrival at the dental office, the burs were opened by the dental technicians, with the packaging materials (described in Table 2) being discarded into the municipal solid waste stream.

Table 1 Weights of bur components and packaging used in the inventory

Component	Weight (g)
Stainless steel	1.05
Glass-fiber-reinforced plastic	2.51
Kraft paper	8.02

During use, the burs were inserted into a dental handpiece which rotated the bur at high speeds ranging up to 400,000 rpm (Franzel 2013). This process only involved energy input, as the handpiece was plugged directly into a standard US socket. The electricity consumed during bur use was not included in the analysis because the electricity required for utilization of burs was assumed to be identical for reused and disposable burs. In practice, however, the electricity consumed by reused and disposable burs may differ based on different tool conditions and use environment.

The burs required sterilization in order to be reused. First, excess debris was removed using an ultrasonic cleaner. After ultrasonic cleaning, the burs were manually cleaned under tap water with a scrubbing brush. Lastly, the burs underwent autoclaving. Both the ultrasonic and autoclave would be utilized by staff when they reached their loading capacity, which were similar in volume. Ultrasonic cleaning, manual cleaning, and autoclaving inputs and outputs were assumed to be equal for each reuse instance. A fully loaded ultrasonic and autoclave consisted of many devices commonly used in dental procedures; further into the "Inventory analysis" section, we discuss allocation methods and loading assumptions for the ultrasonic and autoclave. According to the dental staff, the ultrasonic and autoclave were utilized anywhere from one to three instances on a daily basis, where increased numbers of procedures most significantly correlated with increased utilization rates.

At the Deer Valley Smiles office, the reusable burs were placed into an L&R Quantrex S200 Ultrasonic cleaner (6,885-cm^3 capacity) for approximately 30 min. The ultrasonic cleaner immersed the burs in tap water which concurrently subjected the burs to ultrasonic waves produced by a transducer built into the device's chamber. The 30-min time interval was recommended by the manufacturer and was automatically controlled through the ultrasonic's integrated timer. The L&R Quantrex S200 Ultrasonic cleaner used at Deer Valley Smiles' office typically used 5.2 L of water and 0.172 kWh of electricity. The water and electricity data were obtained from 10 independent trials, where electricity consumption was measured by a P3 International P4400 Kill A Watt Electricity Usage Monitor (i.e., Wattmeter) over the entire 30 min of the cleaning. After cleaning, the ultrasonic's water usage was measured directly by beaker.

After a 30-min period in the ultrasonic cleaner, the burs were then manually cleaned with a scrubbing brush under tap water and then placed into an autoclave-safe pouch. Tap water usage was measured directly as the Deer Valley Smiles staff

Table 2 Inventory data used to construct the dental bur life cycle inventory

Material/process (electricity mix)	Value	LCI database	Used in LC process
Stainless steel hot rolled coil (average European mix)	1.05 g	ELCD 3.0	Manufacturing
Glass-fiber-reinforced plastic (average European mix)	2.51 g	ecoinvent v2.2	Packaging
Kraft paper, unbleached (average European mix)	8.02 g	ecoinvent v2.2	Packaging
Transport, combination truck (average European mix)	0.7 tkm	ecoinvent v2.2	Transport
Transport, aircraft, freight (average European mix)	0.01 tkm	ecoinvent v2.2	Transport
Tap water, at user (average Arizona mix)	5.2 kg	ecoinvent v2.2	Ultrasonic
Electricity (average Arizona mix)	0.172 kWh	ecoinvent v2.2	Ultrasonic
Tap water, at user (average Arizona mix)	0.71 kg	ecoinvent v2.2	Manual cleaning
Tap water, at user (average Arizona mix)	5.8 kg	ecoinvent v2.2	Autoclave
Electricity (average Arizona mix)	0.331 kWh	ecoinvent v2.2	Autoclave
Transport, combination truck (average US mix)	0.0003 tkm	USLCI	Transport
Disposal, steel, 0 % water, to municipal incineration (average Switzerland mix)	8.7 % of waste	ecoinvent v2.2	Disposal
Disposal, inert waste, 0 % water, to inert material landfill (average Switzerland mix)	91.3 % of waste	ecoinvent v2.2	Disposal

ELCD European Reference Life Cycle Database, *USLCI* US Life Cycle Database Inventory

cleaned the burs. Residual water was collected in a plastic basin and then directly measured using a 1-L beaker. Based on 10 trials measuring water usage by beaker, the mean value for water used during manual cleaning was 0.71 L, and the first and third inter-quartile range (IQR) values were 0.64 and 0.75 L, respectively.

After manual cleaning, the burs underwent an autoclave cycle with a Statim 5000, Model #201103 Cassette Autoclave, where the burs were autoclaved for 60 min. This time interval was based on recommended manufacturer's specifications and was automatically controlled through the autoclave's integrated timer. The dental aides at Deer Valley Smiles indicated that the number of burs in the ultrasonic and autoclave cycles ranged anywhere from 10 to 30. Therefore, the maximum number of burs for the ultrasonic and autoclave was assumed to be 30 burs per cycle. Because the autoclave functioned by subjecting the burs (and other dental instruments) to high-pressure saturated steam, both electricity and water inputs were associated with the autoclave's cycle. The manufacturer reported that the amount of water used by the autoclave in one cycle was 5.8 L of water. Autoclave electricity consumption was based on 10 independent trials using a P3 International P4400 Kill A Watt Electricity Usage Monitor. The mean value for electricity consumption was 0.331 kWh (as shown in Table 2), and the first and third IQR values were 0.328 and 0.333 kWh, respectively.

Several aspects related to the inventory of the autoclave and ultrasonic machines were omitted from the system boundary. Inventory related to the manufacturing and production and delivery of the autoclave and ultrasonic machines were omitted from the system boundary because the autoclave and ultrasonic are simultaneously used with other devices not including burs. Based on the omission of the autoclave and ultrasonic from the system boundary, as well as the unpredictable nature of the ultrasonic and autoclave loading contents, it was assumed that autoclave and ultrasonic cycles consisted strictly of dental burs and no other dental devices. However, this practice is not typical for dental offices, as the office would simultaneously use the autoclave and ultrasonic on a variety of other dental instruments, which included scalpels, forceps, bone chisels, and scalers. Subsequently, this assumption yields conservative results, since the LCA impacts resulting from water and energy associated with ultrasonic and autoclave are not allocated across other dental devices.

Single-use burs and burs that had been reused 30 instances would undergo the same disposal process. When marked for disposal, the burs were placed into a general medical waste container, which typically contained other used medical items. Specific to the Deer Valley Smiles office, medical waste was handled by a medical and pharmaceutical recycling company, Stericycle. Waste for the dental office was transported 27 km by truck to Stericycle's local handling facility. The burs would then undergo a medical incineration process.

2.3 Impact assessment

The LCIA was conducted using the TRACI v2.0 developed by the USEPA (TRACI 2013). The following environmental impacts were calculated and reported from TRACI: ozone depletion, global warming, smog, acidification, eutrophication, carcinogenics, non-carcinogenics, respiratory effects, and ecotoxicity.

2.4 Scenario analysis

The results were divided into three scenarios: best-case, mid-case, and worst-case. The scenario analysis varied bur loading of both the ultrasonic and autoclave. As previously stated, the

maximum assumed load for the ultrasonic and autoclave was 30 burs and was considered the best-case scenario. The worst-case scenario of 10 burs per cycle was derived directly from personal consultation with the studied office's dental aides, who claimed that 10 was the lowest number of burs they had used in a single ultrasonic/autoclave cycle. A mid-case scenario of 20 was assumed, which serves as the median between the best- and worst-case scenarios.

3 Results and discussion

When the autoclave and ultrasonic were loaded with 30 burs, reusable burs showed lower life cycle environmental impacts in all TRACI categories (Fig. 4). Results in Fig. 4 represent the best-case scenario and were associated with the ultrasonic and autoclave being used to their most effective extent. Effectiveness was based on their respective loading capacities, which were both assumed to be 30 burs per autoclave and ultrasonic cycle. In the best-case scenario, reused burs exhibited one third the impact of disposable burs in the following LCIA categories: ozone depletion, smog, respiratory effects, and ecotoxicity. In all nine of the impact categories, reused burs had a lower overall impact compared to single-use burs. The global warming impact is characterized by CO_2 equivalent (eq) emissions, which are 1.19 and 0.42 kg CO_2 eq for disposable burs and burs reused 30 instances, respectively. Both the ultrasonic and autoclave were limited in their respective impacts because of their high operating efficiency. The glass-fiber-reinforced plastic used in bur packaging was a significant contributor to most impact categories, including ozone depletion, global warming, eutrophication, and ecotoxicity.

Figure 5 represents a mid-case scenario, which was determined as the sterilization load where reuse performed better than single use in four out of the nine TRACI LCIA categories. The mid-case scenario resulted in the ultrasonic and autoclave being loaded to 66 % capacity, where 20 burs were loaded into the autoclave and ultrasonic per cycle. These impact categories include acidification, eutrophication, carcinogenic, and non-carcinogenics. The global warming impact category values for reusable and single-use burs were similar, where they showed greater than 99.5 % comparability (1.19 and 1.18 kg CO_2 emitted for disposable and reusable, respectively). This was considered a mid-case scenario because four impact categories favored reusable burs (i.e., ozone depletion, smog, respiratory effects, exotoxicity), and four impact categories environmentally favored disposables (i.e., acidification, eutrophication, carcinogenics, and non-carcinogenics), and the final impact category, global warming, was nearly identical for reusable and disposable burs. The mid-case scenario shown in Fig. 5 represents a situation where the ultrasonic and autoclave increased considerably in their respective impacts.

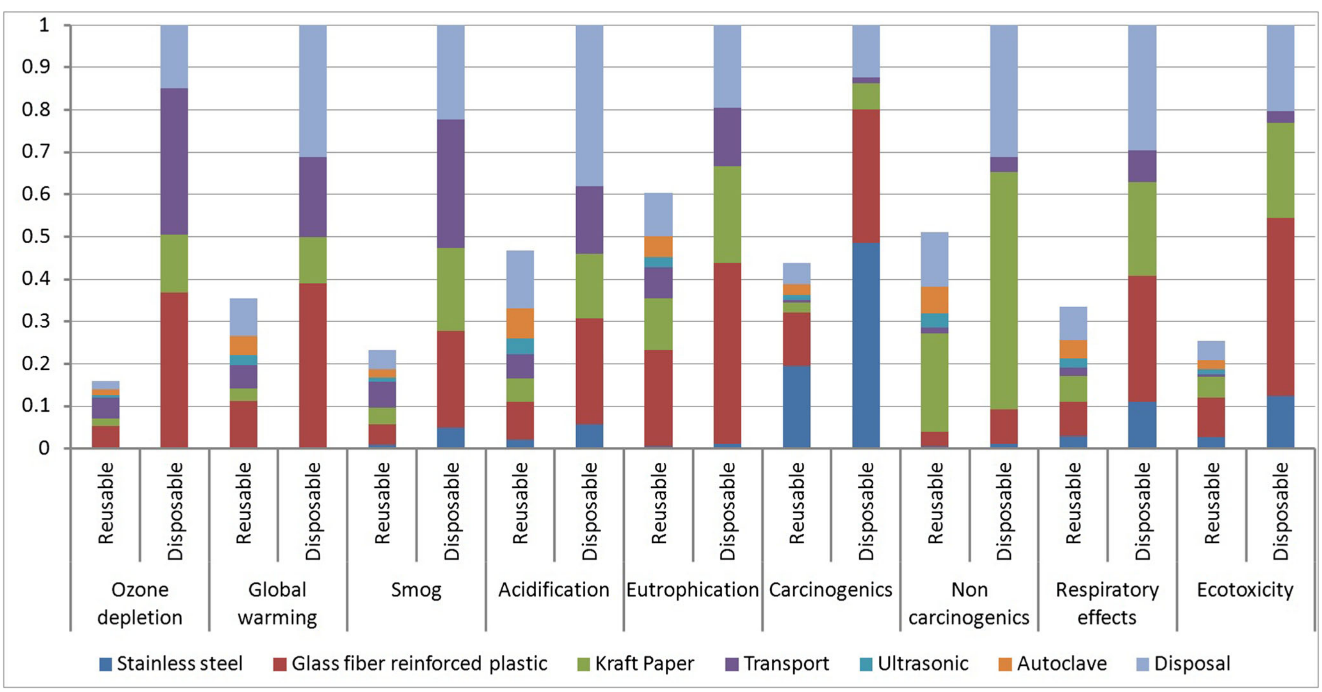

Fig. 4 Best-case scenario for 30 disposable burs versus 1 bur reused 30 instances. Impacts normalized to disposable burs; best-case scenario represents autoclave and ultrasonic cleaning filled to highest capacity, or 30 burs. *Each entry in the legend* represents the upstream data required for each process (e.g., "ultrasonic" includes water and electricity for operating the device)

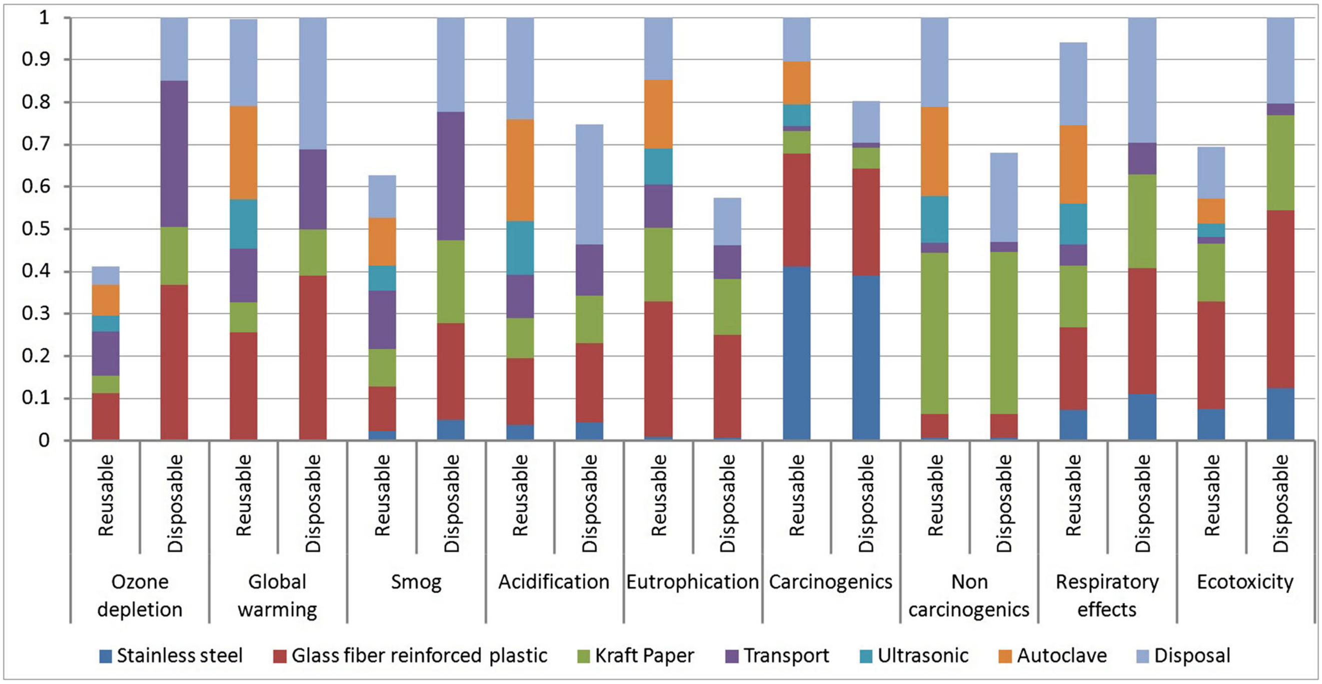

Fig. 5 Mid-case scenario for 30 disposable burs versus 1 bur reused 30 instances. Impacts normalized to the highest impact in each category; mid-case scenario represents the ultrasonic and autoclave being loaded to 66 % capacity, where 20 burs are loaded into the autoclave and ultrasonic per cycle. *Each entry in the legend* represents the upstream data required for each process (e.g., "kraft paper" includes raw materials extraction, paper production, manufacture, and assembly of packaging)

Figure 6 illustrates what is considered a "worst-case scenario" for reusable dental burs. Figure 6 represents a situation where the ultrasonic and autoclave were used at 33 % capacity or eight burs loaded per cycle. In eight of nine TRACI impact categories, reusable dental bur posed more negative environmental impacts than disposable burs. The largest disparity

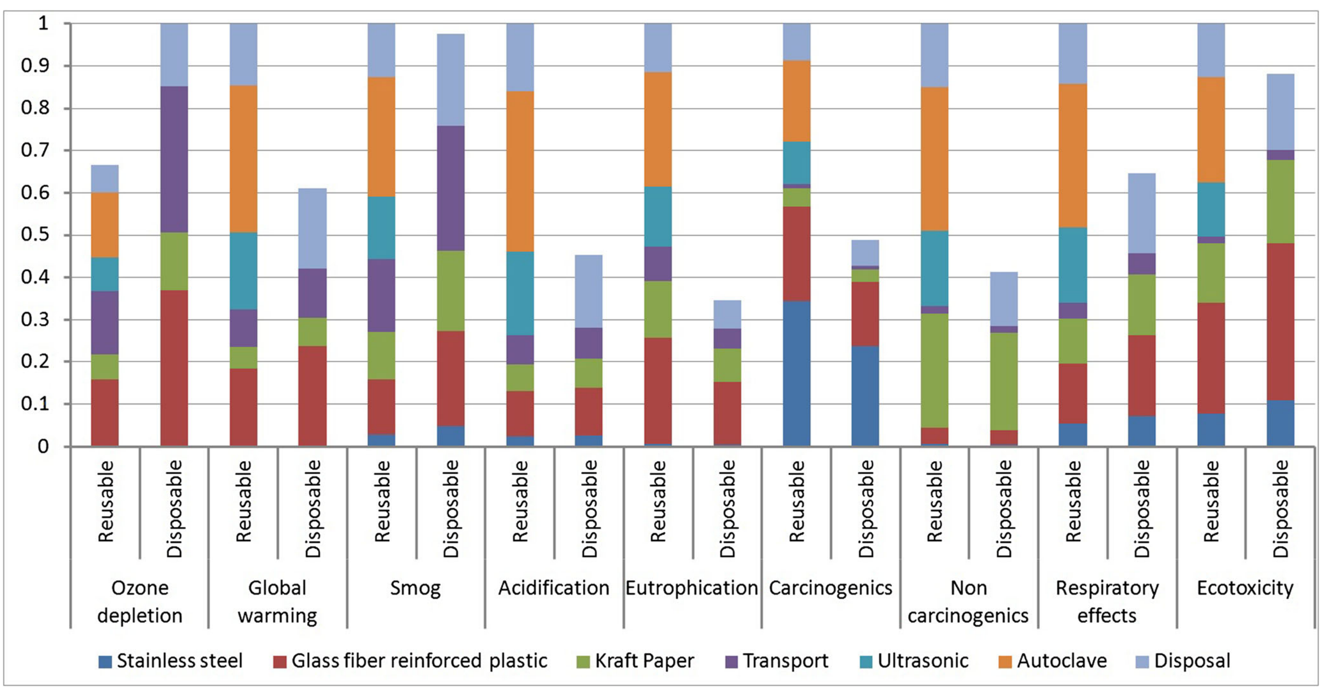

Fig. 6 Worst-case scenario for 30 disposable burs versus 1 bur reused 30 instances. Impacts normalized to the highest impact in each category; worst-case scenario represents the ultrasonic and autoclave being loaded to 33 % capacity, where 10 burs are loaded into the autoclave and ultrasonic per cycle. *Each entry in the legend* represents the upstream data required for each process (e.g., "glass-fiber-reinforced plastic" includes raw materials extraction, plastic production, manufacture, and assembly of packaging)

existed in the eutrophication impact category, with over a 60 % differential. This situation was not ideal, as the ultrasonic and autoclave were utilized at particularly low operating efficiencies. The worst-case scenario shown in Fig. 6 is characterized by high autoclave impact. With the exception of carcinogenics, the autoclave was the most significant driver in all of the impact categories. And while fairly negligible in the best-case and mid-case scenarios, the ultrasonic was significant in many of the impact categories.

The best-case, mid-case, worst-case, and disposable scenarios are aggregated into Fig. 7, which shows the equivalence value for all nine TRACI impact categories. Figure 7 includes all processes and products associated with each scenario. The glass-fiber-reinforced plastic was the most significant driver for most impact categories. The glass-fiber-reinforced plastic was used in the packaging of the burs, where the bur was stored directly in a glass fiber cylindrical tube, which was sealed until the bur's use. In the non-carcinogenics impact category, unbleached kraft paper was the driving factor. The kraft paper was also used in the bur's packaging. Transport by aircraft was significant to impact categories including ozone depletion, global warming, smog, and acidification. For other impact categories, transport was fairly negligible.

More geographically specific inventory data could improve the accuracy of the results. For example, a European electricity mix (provided by ecoinvent v2.2.) was used for electricity generation in bur manufacturing. However, a German electricity mix, or even an electricity mix specific to Minden, Germany, could have given more accurate results. On the other hand, there are many dental practices in cities across the USA, and there are several bur manufacturers around the world. Future work might attempt to assess the average impacts from disposable dental products to evaluate representative industry standards. Additionally, all disposal methods are based on Swiss inventory records, which is due to lack of relevant US disposal life cycle inventory data. Specifically, there is no life cycle inventory database that lists disposal of steel (with 0 % water) to a municipal incinerator located in the USA, and there is no life cycle inventory that lists disposal of inert waste (with 0 % water) to an inert material landfill located in the USA.

4 Conclusions

Operational efficiency of ultrasonic and autoclave cleaning equipment should be emphasized to enhance the environmental performance of bur reuse. Maximizing loading efficiency of the dental cleaning equipment, i.e., the ultrasonic and autoclave, is necessary for reduction of environmental impacts. In fact, improper loading of the ultrasonic and autoclave can lead to greater adverse environmental impacts than if the burs were treated as disposables.

Improvements to the environmental impact of dental burs can be made by targeted improvements to bur packaging. With regard to the best-case scenario presented in Fig. 6, the packaging materials proved to be the most significant contributor to environmental impacts. Therefore, the next logical step after optimizing reuse protocols would be to optimize packaging. The glass-fiber-reinforced plastic contributed most to environmental impacts; other packaging materials or packaging methods might be able to provide similar product

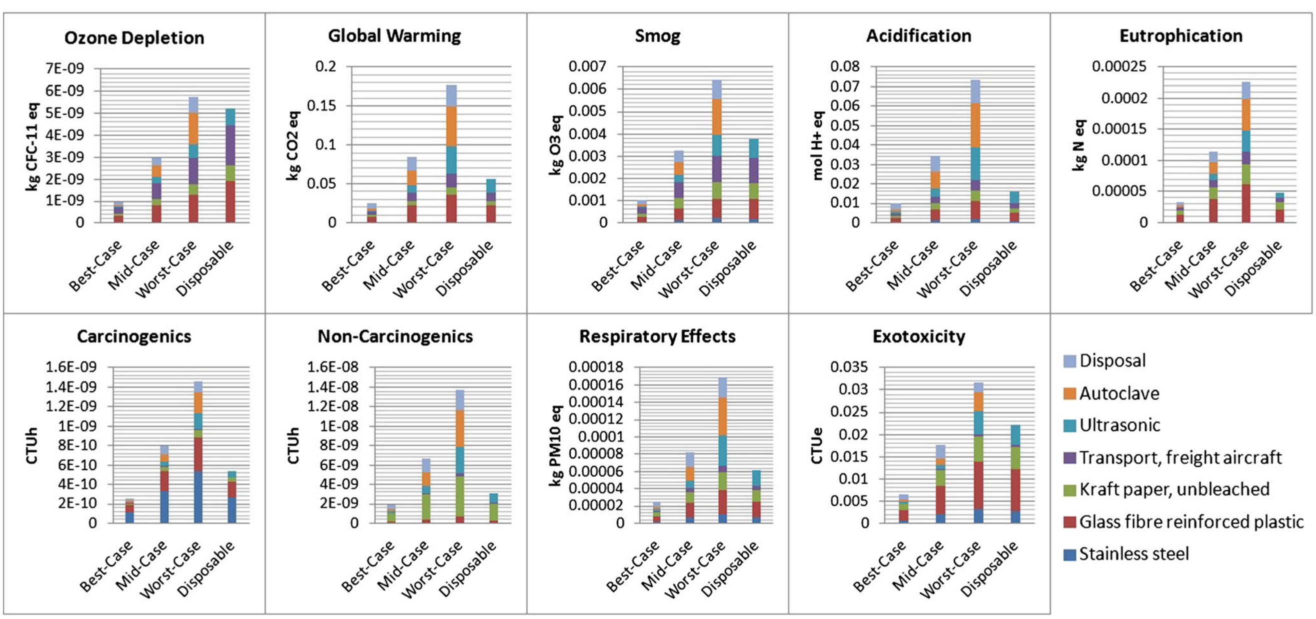

Fig. 7 Summary of results for life cycle impact categories

protection while using less material. Accordingly, future studies should especially focus on glass-fiber-reinforced plastic and its potential substitutes.

Although reusing dental burs will decrease negative environmental impacts attributed to the dental bur supply chain, increased reuse of dental burs is also attributed to a lower level of bur functionality. However, to date, there are no studies citing a rise in adverse patient outcomes with regard to increased instances of bur reuse.

Not all dental offices designate their burs as reusable; rather, the burs are commonly treated as single-use devices. The resulting environmental and economic impacts of burs being designated as reusable are significant, especially when high quantities of burs are used. This study has illustrated and discussed the environmental benefits of designating burs as reusable. Because most dental offices already have bur-ready cleaning equipment (e.g., ultrasound and autoclave) that offices use for cleaning other dental devices, initial capital and future economic costs (i.e., electricity and water) for on-site bur cleaning are minimal. Initial capital costs for an ultrasonic and autoclave can range anywhere from US$3,500 to US$7,000, where increased cost is typically correlated with decreased cleaning time (Statim Autoclaves 2013; Ultrasonic Cleaning Systems 2013). Additionally, a bur's price can range anywhere from US$70 to US$150 (Franzel 2013). Given that hundreds of burs can be used by a single dental office on a monthly basis, breakeven of costs between capital purchase of cleaning equipment and costs for single-use disposable burs can be achieved within only a few years, where increased bur loading in cleaning equipment will decrease the necessary time for to reach breakeven.

The environmental and economic impacts associated with bur reuse are expected to be similar with other dental devices that are designated as disposable but have the capability of being reused. Common dental instruments that are either reusable or disposable include scalpels, forceps, bone chisels, and scalers. Whether these devices are reused or how many instances they are reused are based on the dentist's discretion. Increased instances of reuse for these devices will result in reduced environmental impacts associated with dental device supply chains and have clear economic benefits.

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